United States Department of Agriculture | Forest Service | Northeastern Area State & Private Forestry | 180 Canfield Street Morgantown, WV 26505-3101

File Code: 3400
Date: June 16, 2004

Greg Mollenkopf
Baltimore District
US Army Corps of Engineers
Attn: CENAB-OP-PN
Baltimore, MD 21203

Dear Mr. Mollenkopf:

Enclosed is a hemlock woolly adelgid (HWA) biological evaluation at Raystown Lake. In general, hemlock health conditions range from healthy to moderate decline throughout most of the survey area. Of the 9 stands surveyed, only one stand ranked in the moderate to severe category. HWA population densities throughout the area are highly variable, ranging from none to heavy. HWA densities will continue to fluctuate in the coming years but the impact on hemlock health will continually worsen without intervention.

We recommend the following 2 management actions to protect important hemlock resources at the Raystown Project:

1) Release and establishment of *Sasajiscymnus tsugae* (*S.t.*) (formerly *Pseudoscymnus tsugae*) predatory beetles as a biocontrol in stand 6 where there are healthy HWA populations and no chemically treated trees in close proximity;
2) Chemical treatment of high valued infested hemlock trees in stands 2,3,4,6, and 7 using imidacloprid via. soil injection, soil drench or stem injection as appropriate. Treatment timing for these application methods is spring or fall for soil treatments and fall for stem injections.

Please contact Brad Onken (304-285-1546) if you have any questions concerning this biological evaluation.

Sincerely,

JOHN W. HAZEL
Field Representative MFO

Enclosure

Cc: Dwight Beal, Project Manager, Raystown Lake
Jeff Krause, Wildlife Biologist, Raystown Lake
Noel Schneeberger, AO
Dennis Souto, DFO

Biological Evaluation
of
Hemlock Woolly Adelgid
at
Raystown Lake,
Hesston, Pennsylvania

Prepared by

Bradley Onken, Entomlogist
Karen Felton, Biologist
And
Matthew D. Seese, Biological Science Technician

USDA Forest Service
State and Private Forestry
Forest Health Protection
180 Canfield Street
Morgantown, WV 26505

June 2004

ABSTRACT

In the spring of 2004, USDA Forest Service personnel conducted surveys to evaluate hemlock woolly adelgid (HWA), *Adelges tsugae* population densities at Raystown Lake, and to assess the need for treatment. Current populations are sufficient to impact tree health in some of the areas surveyed. The release and establishment of the predator beetle *Sasajiscymnus tsugae* (*S.t.*) in stand 6 and the use of imidacloprid on infested hemlocks in stands 2, 3, 4, 7 and 10 is recommended.

INTRODUCTION

HEMLOCK WOOLLY ADELGID

Adelgids are small, soft-bodied insects that feed on plant sap. The family is divided into two genera: *Adelges* and *Pineus*. The members of this family feed exclusively on conifers. There are six species of *Adelges* that occur in North America, of which only one is native (Montgomery 1999), the Cooley spruce gall aphid (*Adelges cooleyi*). This adelgid occurs coast to coast in northern North America. Its primary hosts are recorded as white (*Picea glauca*), blue (*Picea pungens*), Sitka (*Picea sitchensis*), and Engelmann (*Picea engelmannii*) spruce (Baker 1972). It has an alternate host, Douglas fir (*Pseudotsuga menziesii*). There are 10 species of *Pineus* that occur in North America, of which seven are native. Four of these the pine bark adelgid (*Pineus strobi*); the pine leaf adelgid (*P. pinifoliae)*; the red spruce adelgid (*P. floccus*); and the spruce gall adelgid (*P. similes*) seem to be indigenous to eastern North America (Drooz 1989, Montgomery 1999). These species attack eastern white pine (*Pinus strobus*), red spruce (*Picea rubens*), and black spruce (*Picea mariana*) but seldom cause extensive damage (Drooz 1989, Montgomery 1999). Little is known about the population dynamics, ecological role, or the predator and parasite complex associated with these native adelgids.

Native to Asia, the hemlock woolly adelgid (*Adelges tsugae)*, is a pest of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliana*) (Onken et al. 1999) both of which are considered highly susceptible to the adelgid, with no documented resistance (Bentz et al. 2002). The latter tree species is found only in the southern region of the Appalachian Mountains (Onken et al. 1999). The HWA is currently established in 16 Eastern States from Georgia to Maine, and tree decline and mortality have increased at an accelerated rate since the late 1980s. For example, in the Shenandoah National Park (SNP), hemlock crown health has declined since the early 1990s. In 1990, greater than 77 percent of the hemlocks sampled were in a "healthy" condition; by 1999, less than 10 percent were in a "healthy" condition (Akerson and Hunt 1998). In another study at SNP, tree mortality significantly increased from an initial 8 percent in 1990 to nearly 50 percent in 2000 (Bair 2002). In New Jersey less than 13 percent of stands surveyed in 1991 remain healthy. Twelve years after initial HWA infestations, tree mortality has reached more than 90% in some New Jersey hemlock stands (Mayer et al 2002).

The hemlock woolly adelgid is parthenogenetic (an all-female population with asexual reproduction) that has six stages of development: the egg, four nymphal instars, and the adult, and two generations a year on hemlock; each adult adelgid can produce 50 to 300 eggs in her lifetime (McClure 1989, 1995). The hemlock woolly adelgid also has a winged form that is produced by the spring generation. This form must complete part of its life cycle on spruce. The apparent lack of a suitable spruce host for this form in eastern North America results in a substantial loss of adelgids each year (McClure 1992b). Although natural mortality in HWA populations is commonly between 30 to 60 percent (McClure 1989, 1996), the reproduction potential of this insect remains high. Other mortality is

generally attributed to two likely causes: 1) an extended period of cold temperatures or rapid temperature changes that coincides with a susceptible period of development for the adelgid, and/or 2) a sufficient loss in the nutritional quality and quantity of the food source, which is associated with the decline in health and vigor of the host tree (McClure 1996, Onken et al. 1999). Adelgid feeding can kill a mature tree in about 5 to 7 years (McClure et al. 2001). This tiny insect (~ 1 mm) feeds on all life stages of hemlock, from seedling to mature, old growth tree. The first instar nymphs, called crawlers, search for suitable sites at the base of the hemlock needles, and insert their feeding stylets into the young hemlock twigs and are committed to that feeding site throughout the remainder of its development. The stylet bundle is more than three times the length of the insect and penetrates deep within the plant tissues. HWA does not deplete nutrients directly by feeding on the sap, but rather by depleting the food reserves from the tree's storage cells (McClure et al. 2001). Dispersal and movement of HWA during its egg and mobile first instar stages is associated with wind, birds, deer, and other forest dwelling mammals. Humans also move the adelgid during logging and recreational activities and movement of infested nursery stock (McClure 1995). Natural enemies capable of maintaining low-level HWA populations are nonexistent in eastern North America (Van Driesche et al. 1996, Wallace and Hain 1998).

HWA was first reported in the western U.S. in the 1920s (Annand 1924, McClure 2001). HWA populations on western tree species, including western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*), appear to be innocuous; these tree species are believed to be resistant because little damage has been reported (McClure 2001). Unfortunately, both these trees are of limited value for hybridization and planting due to their poor adaptation to the east coast environment (Bentz et al. 2002). In the East, HWA was first reported in 1951 near Richmond, Virginia. It was considered to be more of an urban landscape pest and was controlled using a variety of insecticides applied with ground spraying equipment. Observations of the adelgid were periodically reported in several Mid-Atlantic States in the 1960s and 1970s but it was not until the 1980s that HWA populations began to surge and spread northward to New England at an alarming rate. By the late 1980s to early 1990s, infestations of HWA were reported to be causing extensive hemlock decline and tree mortality in hemlock forests throughout the East (McClure 2001).

HEMLOCK IMPORTANCE

Eastern hemlock is an extremely shade tolerant tree species, capable of surviving for as long as 350 years underneath a shaded forest canopy (Quimby, 1996). It is a slow-growing long-lived tree. It may take 250-300 years to reach maturity and may live for 800 years or more (Godman and Lancaster 1990). Eastern hemlock forests create distinctive microclimates and provide important habitat for a variety of wildlife, such as birds, fish, invertebrates, amphibians, reptiles and mammals. In the Northeast, 96 bird and 47 mammal species are associated with hemlock forests at some point during their life (Yamasaki et al. 2000).

Hemlocks located along the shoreline of the lake are of aesthetic value and provide valuable wildlife habitat along the small streams and spring channels. Because of the limited hemlock habitat at Raystown Lake, resource managers have expressed a high priority to protect these trees.

HWA HISTORY AND OTHER STRESSORS AFFECTING HEMLOCK HEALTH CONDITIONS AT RAYSTOWN LAKE

HWA was first discovered at Raystown Lake in 1999 at the northern end of the lake. In 2002, a survey was conducted to determine the extent and magnitude of HWA infestations. Over 160 acres of hemlocks were surveyed and about 144 acres were determined to be infested with HWA.

The impacts of HWA and the droughts of recent years have stressed hemlock resources at Raystown Lake. So far, over 100 mature hemlock trees have succumbed.

In the fall of 2003, over 200 trees in stand 1 received trunk injections of a systemic insecticide imidacloprid (Pointer®), at 5 percent active ingredient to control HWA. In the spring of 2004, approximately 1,000 additional trees were treated in stands 1-4, 7, and 10 using the same treatment.

METHODS

Live hemlock trees (> 6" dbh) were randomly selected for inspection within the survey areas. An assessment of tree vigor, branch tip dieback, crown position, dbh, and HWA population densities was conducted of each tree. Branch samples were collected and returned to the lab to evaluate viability of HWA populations and degree of winter mortality.

HWA infestation levels were designated as heavy, moderate, light or none based on the criteria listed below:

HWA – Based on the percentage of tips with adelgid present per 30 centimeters of hemlock twig length: Heavy (H) = (>50% infested)
Moderate (M) = (50% to 25% infested)
Light (L) = (<25% infested)
None (N) = (0% infested)

Vigor indicates the health of the tree crown based on the rating below:

Healthy (H) = tree appears to be in reasonably good health: less than 10% branch or twig mortality, discoloration, or dwarfed leaves present

Light Decline (LD) = branch mortality, twig dieback, foliage discoloration, or dwarfed leaves present on 10-25% of the crown

Moderate Decline (MD) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 26-50% of crown

Moderate-Severe Decline (MS) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 51-75% of crown

Severe Decline (SD) = more than 75% of the crown with branch mortality, dieback, discoloration or leaf dwarfing, but foliage still present indicating that the tree is alive

RESULTS

The survey areas are represented in Figure 1. The results of the survey are summarized in Table 1. Hemlock woolly adelgid infestations and tree health ratings are variable from stand to stand and even tree to tree throughout the survey area. HWA winter mortality at Raystown Lake averaged just fewer than 20 percent.

In stand 1, trees are generally in moderate health. Populations of HWA has generally collapsed as no adelgids were observed on either treated (fall 2003) or non-treated trees.

In stand 2, trees are generally in moderate health and HWA infestations ranged from light to heavy.

In stands 3, 4, 6 and 7, trees are healthy and HWA infestations are generally moderate to heavy.

In stand 8, trees are healthy and HWA population densities are generally light to none.

No individual tree data was collected for stand 9. Trees in this area were very scattered and generally in severe decline.

In stand 10, trees are generally in moderate to severe decline and HWA population densities are light to none.

Another non-native hemlock pest, the shortneedle evergreen scale (a circular hemlock scale), *Nuculaspis tsugae* was also observed but at extremely low densities and not of concern at this time. This circular scale is native to Japan and attacks the eastern and Carolina hemlock (Johnson and Lyon 1988, McClure 2002a). The circular hemlock scale was first reported in the United States, in 1910. The shortneedle evergreen scale is now known to occur in Connecticut, Maryland, New Jersey, Rhode Island, and New York (McClure 2002a), and its hosts other than hemlock include fir, cedar (*Cedrus* species), spruce and yew (*Taxus* species) (Drooz 1989). Circular hemlock scale is far less abundant and generally out competed by other exotic scales.

Figure 1. Hemlock woolly adelgid survey locations at Raystown Lake, Hesston, PA – Stands 1,2,3,4,6,7,8,9,10 – Spring 2004.

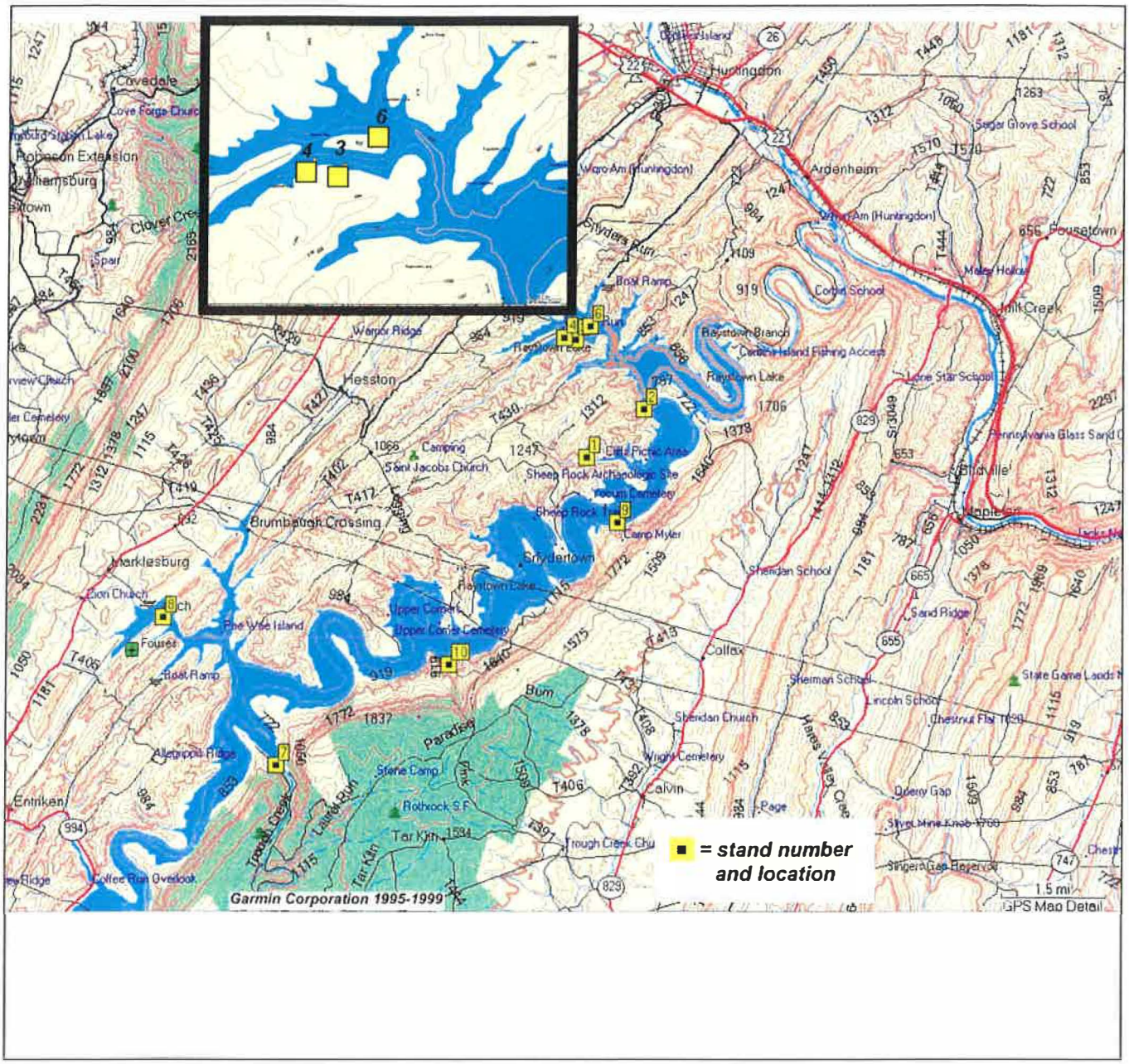

Table 1. *Summary of the hemlock woolly adelgid results for hemlock stands 1, 2, 3, 4, 6, 7, 8, 10 at Raystown Lake, April 2004.*

TREE #	LOCATION	DBH	CROWN POSITION	HWA INFEST LEVEL	DEAD TIP %	VIGOR
1	Stand 1	6	S	NONE	16	MS
2	Stand 1	6	I	NONE	10	LD
3	Stand 1	8	S	NONE	0	LD
4	Stand 1	10	S	NONE	10	M
5	Stand 1	10	S	NONE	10	M
6	Stand 1	8	S	NONE	5	M
7	Stand 1	10	S	NONE	0	M
8	Stand 1	10	I	NONE	4	M
9*	Stand 1	12	CD	NONE	18	M
10*	Stand 1	12	I	NONE	11	M
11*	Stand 1	14	I	NONE	9	M
1	Stand 2	10	D	LIGHT	32	M
2	Stand 2	8	I	LIGHT	6	M
3	Stand 2	10	CD	MODERATE	0	LD
4	Stand 2	14	D	LIGHT	21	LD
5	Stand 2	14	D	LIGHT	15	M
6	Stand 2	24	D	HEAVY	6	M
7	Stand 2	8	CD	HEAVY	14	H
1	Stand 3	14	CD	NONE	0	H
2	Stand 3	8	I	HEAVY	0	H
3	Stand 3	10	CD	HEAVY	15	LD
4	Stand 3	6	S	HEAVY	0	H
5	Stand 3	12	CD	LIGHT	0	H
1	Stand 4	10	CD	HEAVY	0	H
2	Stand 4	8	I	LOW	0	H
3	Stand 4	10	CD	LOW	0	H
4	Stand 4	8	S	HEAVY	3	H
5	Stand 4	10	CD	NONE	11	H
1	Stand 6	12	CD	MODERATE	8	H
2	Stand 6	12	CD	HEAVY	0	H
3	Stand 6	14	D	LOW	0	LD
4	Stand 6	10	D	HEAVY	0	H
5	Stand 6	12	CD	HEAVY	2	H
1	Stand 7	14	CD	HEAVY	2	H
2	Stand 7	10	CD	HEAVY	0	H

TREE #	LOCATION	DBH[1]	CROWN POSITION[2]	HWA INFEST LEVEL[4]	DEAD TIP %[5]	VIGOR[6]
3	Stand 7	10	I	NONE	0	H
4	Stand 7	16	D	MODERATE	0	H
5	Stand 7	14	CD	MODERATE	5	H
6	Stand 7	24	D	HEAVY	0	H
1	Stand 8	4	S	NONE	0	H
2	Stand 8	4	S	NONE	0	H
3	Stand 8	12	CD	NONE	0	H
4	Stand 8	6	I	NONE	0	H
5	Stand 8	8	CD	LIGHT	0	H
1	Stand 10	12	I	NONE	8	MS
2	Stand 10	12	I	NONE	6	M
3	Stand 10	8	S	MODERATE	3	M
4	Stand 10	4	S	LIGHT	16	MS
5	Stand 10	10	I	NONE	11	M

*Tree received chemical stem injection

[1]-DBH= estimated tree diameter at breast height to nearest inch

[2]-Crown position: D=dominate, CD=codominate, I=intermediate, S=suppressed, OG=open grown

[3]-Percentage of tips with adelgid present per 30 centimeters (cm) of hemlock twig length: Heavy = (>50% infested), Moderate = (50% to 25% infested), Light = (<25% infested), None = (0% infested)

[4]-Scale presence based on visual estimates from 30 cm length of hemlock branch: HEAVY = (>1/needle on average), MODERATE = (1/needle on average), LIGHT = (<1/needle on average), NONE = (0% infested)

[5]-Precentage of dead tips per 30 centimeters of hemlock twig length

[6]- Vigor = Tree crown health:

Healthy (H) = tree appears to be in reasonably good health: less than 10% branch or twig mortality, discoloration, or dwarfed leaves present

Light Decline (LD) = branch mortality, twig dieback, foliage discoloration, or dwarfed leaves present on 10-25% of the crown

Moderate Decline (MD) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 26-50% of crown

Moderate-Severe Decline (MS) = branch morality, twig dieback, foliage discoloration or dwarfed leaves on 51-75% of crown

Severe Decline (SD) = more than 75% of the crown with branch mortality, dieback, discoloration or leaf dwarfing, but foliage still present indicating that the tree is alive

DISCUSSION

Tree health and HWA population densities are highly variable within the hemlock stands surveyed at Raystown Lake. Stands 3, 4, 6 and 7 have trees that are basically in good health and HWA infestations are moderate to heavy. In stands 1 and 10 where tree health is in moderate to severe decline and HWA population densities range from none to heavy. There has been a loss of approximately 100 mature hemlock trees at Raystown Lake. Droughty conditions that have occurred periodically since 1999 have likely contributed to the overall stress on hemlock trees in the Project area.

Management Considerations

Management options for preserving hemlock stands are limited by the biology and feeding behavior of HWA, pest population densities, site conditions (i.e. proximity to streams), and limited chemical and application technology currently available.

Chemical treatments: Aerial spray using horticultural oil or insecticidal soap is not an effective treatment because it fails to provide the needed "saturation" coverage necessary to ensure that the insecticide adequately covers the insect. Aerial spraying with more toxic insecticides (e.g. malathion or diazinon) would have very significant, unacceptable impacts on a wide range of non-target insects and other animals and limited control benefits (Evans 2000). Application of insecticides using ground spraying equipment is limited to areas accessible to heavy hydraulic spray equipment and areas where over spray or run off would not contaminate streams, lakes or ponds. Tree injections using systemic insecticides such as imidacloprid has not been proven effective at controlling HWA when trees are in severe decline however soil injection and soil drench methods has had some success.

Biological control: There are no known pheromones for HWA. Successful establishment of predators of HWA such as *Sasajiscymnus tsugae* (*S.t*) (formerly *Pseudoscymnus tsugae*) requires a viable and healthy population of adelgids, which ironically is linked to healthy hemlocks. These predator beetles are not expected to have an immediate effect on HWA populations at the stand level but are expected to provide longer term control as part of a self perpetuating natural enemy complex. Release of *S.t.* beetles should not take place in close proximity of any hemlock trees that have or will receive chemical treatments because of the effect of the chemical insecticide on the beetle itself, and also for the reduction in availability of future healthy HWA as a food source.

Considering the above limitations, foliar ground spraying using hydraulic sprayers is not feasible in any of the surveyed areas because of limited access and stream/lake-side locations. Feasible management options are 1) the release of *S.t.* beetles in areas where there are healthy HWA population densities and no chemically treated trees in close proximity; 2) use backpack sprayers using horticultural oil on hemlock seedlings and saplings where protecting hemlock regeneration is important; and 3) the use of systemic insecticides, particularly the use of imidacloprid on infested mature hemlocks.

***Sasajiscymnus tsugae* beetles**

This option involves the release of laboratory reared *Sasajiscymnus tsugae* beetles in hemlock woolly adelgid infested hemlock trees for the purpose of accelerating the establishment and evaluation of this predator beetle. HWA populations must be at a level that can sustain the beetles. Releases would be conducted sometime in April/May 2004. Monitoring and evaluation efforts would continue for 3 years after release for the purpose of documenting the establishment and dispersal of the beetle and evaluating its effectiveness in reducing HWA population densities and protecting hemlock health. The New Jersey

Department of Agriculture and Eco-Scientific Solutions (Scranton, PA) are currently rearing *S. tsugae* for this purpose. Additional releases of *S. tsugae* beetles within a site are possible in the future based on beetle availability and monitoring results.

Sasajiscymnus tsugae is a tiny (~ 2 mm) coccinellid (ladybird) beetle native to Japan (Sasaji and McClure 1997), that was imported into Connecticut in 1994 (McClure and Cheah 1998), screened in quarantine, and evaluated to determine its suitability as a biocontrol agent for HWA in this country (Evans 2000). The life cycle of *S. tsugae* consists of the egg, four larval instars, the pupa and the adult. Three overlapping generations per year are produced, and these coincide well with the two HWA generations. Adult and larval beetles feed on all life stages of the HWA (Hennessey and McClure 1995). Host suitability tests (tests that determine whether an agent can complete development and reproduce), choice feeding tests, and host acceptance tests (tests that determine whether an agent will feed or reproduce on a host) indicate that *S. tsugae* will feed and develop on other adelgid species, including balsam woolly adelgid and white pine adelgid (McClure and Cheah 1998). Under no choice testing and starving conditions, *S. tsugae* may attack other related prey such as the woolly alder aphid (*Prociphilus tesselatus*) but can not reproduce on a diet of non-adelgid prey (Butin et al. 2002). Extensive laboratory and field tests in Connecticut have demonstrated *S. tsugae* to be an excellent natural enemy of HWA (Cheah 1998). In 1995, the USDA Animal and Plant Health Inspection Service (APHIS) issued Permit Number 950678 to the Connecticut Agricultural Experiment Station to release *S. tsugae* in Connecticut (Evans 2000). Since 1995 nearly 1 million *S. tsugae* have been released in 15 eastern states.

Chemical systemic treatments have or will take place in all the surveyed stands, except for stands 6, 8, and 9. Only stand 6 has high enough HWA population densities to provide for a successful chance of establishment of the *Sasajiscymnus tsugae* beetles.

Systemic Insecticides

Several types of systemic insecticides can be injected (e.g. imidacloprid, bidrin or Metasystox-R®) or implanted (e.g. acephate) into hemlock trees, and another (Merit®) can be applied as a soil drench or injected into to the soil around hemlock trees. These insecticides are absorbed and transported by the vascular system of the tree to feeding adelgids and will effectively suppress HWA populations (Doccola et al. 2003, Webb et al. 2003, Evans 2000, Steward and Horner 1994, McClure 1992a). Soil injection can cause leaching of the insecticide into the soil profile and groundwater (McAvoy et al. 2002) and should not be used in areas where this is a concern, such as along creeks. Of the trunk injections systemic insecticides available only imidacloprid under the trade names Pointer®, IMA-jet® and Imicide® are currently labeled for tree injection for the control of adelgids. Acephate controls adelgids and scale pests and is available as a trunk implant under the trade name ACECAP®.

Imidacloprid

Imidacloprid is a relatively new insecticide in the family of chemicals called neonicotinoids (Felsot 2001) in the chloronicotinyl subgroup (USDA Animal and Plant Health Inspection Service 2002). It has a mode of action similar to that of the botanical product nicotine, functioning as a fast-acting insect neurotoxicant (Schroeder and Flattum 1984) that binds to the nicotinergic receptor sites in the postsynaptic membrane of the insect nerve (USDA Animal and Plant Health Inspection Service 2002), mimicking the action of acetylcholine, and thereby heightening, then blocking, the firing of the postsynaptic receptors with increasing doses (Schroeder and Flattum 1984, Felsot 2001). Because

imidacloprid is slowly degraded in the insect, it causes substantial disorder within the nervous system, leading in most cases to death (Mullins 1993, Smith and Krischik 1999).

Imidacloprid is considered to have low to moderate mammalian toxicity (Mullins 1993), largely because it does not bind nerve receptors in mammals sufficiently to trigger nervous activity (Felsot 2001). The selective toxicity of imidacloprid is perhaps best illustrated by its use in flea treatments approved for cats and dogs. Advantage® is applied directly to the animal's skin; this preparation carries very little, if any, risk to the animal or to the people, including children, who may handle the animal (USDA Animal and Plant Health Inspection Service 2002). Chronic (repeated dose) toxicity studies have demonstrated that imidacloprid is not carcinogenic and is not mutagenic and demonstrates no primary reproductive toxicity (Mullins 1993). In studies of metabolic fate in rats, imidacloprid was rapidly absorbed and eliminated in the excreta (90 percent of the dose within 24 hours) with little bioaccumulation (0.5 percent of the dose after 48 hours) and no biologically significant differences occurring between sexes, dose level, and route of administration (USDA Animal and Plant Health Inspection Service 2002). Imidacloprid is an insecticide exhibiting both systemic and contact activity. The spectrum of activity primarily includes sucking insects (aphids, whiteflies, leaf and plant hoppers, thrips, plant bugs, and scales), many Coleopteran species, and selected species of Diptera and Lepidoptera. Activity has also been demonstrated for ants (Hymenoptera); termites (Isoptera); and cockroaches, grasshoppers, and crickets (Orthoptera). No activity has been demonstrated against nematodes or spider mites (Mullins 1993). In spider mites, imidacloprid has been demonstrated to cause an egg-laying enhancement (James and Price 2002). Since spider mites can be a problem in hemlock, any imidacloprid-treated tree should be carefully monitored for increases in mite populations.

Little is known about the biotransformation and bioactivity of the metabolites of imidacloprid in hemlock. What is known is that trunk-injected imidacloprid generally requires a week or longer to provide adelgid control, with protection lasting for up to 2 years (Tater et al. 1998, Silcox 2002). The soil injection or soil drench methods of imidacloprid treatments take several months for translocation to occur but provides better consistency in treatment efficacy when compared to stem injections.

RECOMMENDATIONS

Feasible management options at Raystown Lake are 1) the release of *S.t.* beetles in areas in stand 6 where there are healthy HWA population densities and no treated trees in close proximity and 2) the use of systemic insecticides in surveyed stands 2, 3, 4, 6, and 7. Where possible, soil injections are preferred over stem injections for better consistency in treatment efficacy of HWA population densities. Merit® applied at 1 ounce per 30 cumulative inches of trunk diameter (dbh) is recommended for the soil injections, and treatment timing should be in the spring or fall. The insecticide recommended for the stem injections is IMA-jet® at 5% active ingredient with the number of application sites determined by dbh. Criteria for number of application sites is as follows: 4 application sites for 6-16 inches dbh, then add one additional application site for each additional 4 inches of dbh. Recommended treatment timing for stem injections is in the fall.

With treatment options comes the potential for non-target effects; land managers must balance the risk of these effects with the potential benefits that come with the control of the HWA. Although broad spectrum insecticides could be injected into the soil around the base of infested trees, there is some risk of minor soil leaching with imidacloprid depending on soil type. As a best management practice, we are recommending that hemlocks within 50 feet of open water be treated with a stem injection rather than a soil treatment. Ground spraying using horticultural oil to protect hemlock seedlings and saplings by means of a backpack sprayer is a viable option in areas where protecting younger hemlocks is desirable.

Resource managers should annually monitor tree health and adelgid conditions, as any treatment intervention action undertaken will require a vigilant monitoring and treatment program until sufficient biological control agents are established.

REFERENCES

Akerson, J. and G. Hunt. 1998. HWA status at the Shenandoah National Park. USDA, Forest Service. Hemlock Woolly Adelgid Newsletter # 3: 10-11.

Annand, P.N. 1924. A new species of *Adelges* (Hemiptera: Phylloxeridae). Pan-Pac. Entomol. 1: 79-82.

Avery, M.L., D.G. Decker, D.L. Fisher and T. R. Stafford. 1993. Response of captive blackbirds to the new insecticidal seed treatment. J. Wildl. Manage. 57(3): 652-656.

Bair, M.W. 2002. Eastern Hemlock (*Tsuga Canadensis*) Mortality in Shenandoah National Park. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 62-66p.

Baker, W.L. 1972. Eastern forest insects. USDA, Forest Service. Miscellaneous Publication No. 1175. 642 p.

Battles, J.J., N. Cleavitt, T.J. Fahey, and R.A.Evans. 2000. Vegetation composition and structure in two hemlock stands threatened by hemlock woolly adelgid. In: Proceedings of a Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America, edited by K.A. McManus, K.S. Shields, and D.R. Souto. Pp.55-61.

Bentz, S.E., L.G.H. Riedel, M.R. Pooler, and A. Townsend. 2002. Hybridization and self-compatibility in controlled pollinations of eastern north American and asian hemlock (*Tsuga*) species. Journal of Arboriculture 28(4): 200-205.

Butin, E., M. Montgomery, N. Havill, and J. Elkinton. 2002. Pre-release host range assessment for classical biological controls: Experience with predators for the hemlock woolly adelgid. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 205-213 p.

Chaney, W.R. 1986. Anatomy and physiology related to chemical movement in trees. Journal of Arboriculture 12(4): 85-91.

Cheah, C.C. 1998. Establishing *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae) as a biological control agent for hemlock woolly adelgid. Environmental Assessment prepared by the Connecticut Agricultural Experiment Station. Unpub. Report. 6 p.

Cheah, C. A. S.-J. and M.S. McClure. 2000. Seasonal synchrony of life cycles between the exotic predator, Pseudoscymnus tsugae (Coleoptera: Coccinellidae) and its prey, the hemlock woolly adelgid Adelges tsugae (Homoptera: Adelgidae). Agric. and For. Entom. 2:241-251.

Doccola, J.J. P.M. Wild, I. Ramasamy, P. Castillo, and C. Taylor. 2003. Efficacy of arborjet viper microinjections in the management of hemlock woolly adelgid. Journal of Arboriculture. 29(6): 327-330.

Drooz, A.T. 1989. Insects of eastern forests. USDA, Forest Service. Micellaneous Publication No. 1426. 608 p.

Evans, R.A. 2000. Draft Environmental Assessment: for the Release and Establishment of *Pseudoscymnus tsugae* (Coleoptera: Coccinellidae) as a Biological Control Agent for Hemlock Woolly Adelgid (*Adelges tsugae*) at the Delaware Water Gap National Recreation Area. USDI, National Park Service, Northeastern Region. 23 p.

Evans, R.A. 2003. Hemlock Ecosystems and Hemlock Woolly Adelgid at Delaware Water Gap National Recreation Area. USDI, National Park Service, Northeastern Region. 20p.

Felsot, A. 2001. Admiring Risk Reduction: Does Imidacloprid have what it takes? Agrichemical and Environmental News 186: 2-13.

Godman, R.M. and K. Lancaster. 1990. *Tsuga canadensis* (l.) Carr., eastern hemlock. In: R.M. Burns and B.H. Honkala, eds. Silvics of North America, vol.1, conifers. USDA Forest Service, Agriculture Handbook No. 654. pp. 604-612.

Helms, J.A., ed. 1998. The dictionary of forestry. The Society of American Foresters. Bethesda, MD.

Hennessey, R.D. and M.S. McClure. 1995. Field release of a non-indigenous lady beetle, *Pseudoscymnus* sp. (Coleoptera: Coccinellidae), for biological control of hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae). Environmental Assessment prepared by USDA, Animal and Plant Health Inspection Service, Riverdale, MD. Unpub. Report. 6 p.

Hepting, G.H. 1971. Diseases of forest and shade trees of the United States. USDA Forest Service, Agricultural Handbook 386. 488-491.

James, D.G. and T.S. Price. 2002. Imidacloprid boosts TSSM egg production. Agrichemical and Environmental News 189: 1-11.

Mayer, M., R. Chianese, T. Scudder, J. White, K. Vongpaseuth, and R. Ward. 2002. Thirteen Years of Monitoring the Hemlock Woolly Adelgid In New jersey Forests. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 50-60 p.

McAvoy, T., W. Mays, S.M. Salom and L.T. Kok. 2002. Preliminary report of the impact of Merit (Imidacloprid) on hemlock woolly adelgid (Adelges tsugae) and non-target species. Department of Entomology, Virginia Polytech Institute and State University, Blacksburg, VA. Unpub. Report. 14 p.

McClure, M.S. 1989. Evidence of a polymorphic life cycle in the hemlock woolly adelgid, *Adelges tsugae* (Homoptera: Adelgidae). Ann. Entom. Soc. Am. 82:50-54.

McClure, M.S. 1992a. Effects of implanted and injected pesticide and fertilizers on the survival of Adelges tsugae (Homoptera: Adelgidae) and on the growth of Tsuga canadensis. Journal Econ. Entomol. 85(2) 468-472.

McClure, M.S. 1992b. Hemlock woolly adelgid. American Nurseryman 175(6): 82-89.

McClure, M.S. 1995. Managing hemlock woolly adelgid in ornamental landscapes. Bulletin 925. Connecticut Agricultural Experiment Station. 7 p.

McClure, M.S. 1996. Biology of *Adelges tsugae* and its potential for spread in the Northeastern United States. In: Salom, S.M., T.C. Tigner, and R.C. Reardon, (Eds.), Proceedings, First hemlock woolly adelgid review, 12 October, 1995, Charlottesville, VA. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-10: 16-25.

McClure, M.S. 2001. Biological control of hemlock woolly adelgid in the Eastern United States. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-2000-08. 10 p.

McClure, M.S. and C.A.S-J. Cheah. 1998. Released Japanese ladybugs are multiplying and killing hemlock woolly adelgids. Frontiers of Plant Science. 50(2): 6-8 p.

McClure, M.S. and C.A.S-J. Cheah. 2002. Establishing Pseudoscymnus tsugae Sasaji and McClure (Coleoptera:Coccinellidae) for the biological control of the hemlock woolly adelgid, Adelges tsugae, Annand (Homoptera:Adelgidae), in the Eastern United States. In: Onken, B., R. Reardon, and J. Lashomb (Eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 351-352 p.

McClure, M.S., S.M. Salom, and K.S. Shields. 2001. Hemlock woolly adelgid. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-2001-03. 14 p.

Millington, W. 1989. Hemlock woolly adelgid infestations discovered. Fall Newsletter of the Research and Resource Planning Division of Delaware Water Gap National Recreation Area.

Montgomery, M.E. 1999. Woolly adelgids in the southern Appalachians: Why they are harmful and prospects for control. In: Gibson, P. and C. Parker, (Eds.), Proceedings of the Appalachian biological control initiative workshop. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-98-14. 59 p.

Montgomery, M.E. and S.M. Lyons. 1996. Natural enemies of adelgids in North America: Their prospect for biological control of *Adelges tsugae* (Homoptera: Adelgidae). In: Salom, S.M., T.C. Tigner, and R.C. Reardon, (Eds.), Proceedings, First hemlock woolly adelgid review, 12 October, 1995, Charlottesville, VA. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-10: 89-102.

Mullins, J.W. 1993. Imidacloprid: a new nitroguanidien insecticide. In: Duke, S.O., J.J. Menn, and J.R. Plimmer (eds.), Pest control with enhanced environmental safety. American Chemical Society Symposium, ASC, Washington DC: 183-189.

Myers, W.L. and R.R. Irish. 1981. Vegetation survey of Delaware Water Gap National Recreation Area. Final Report, USDAI National Park Service.

Onken, B., D. Souto, and R. Rhea. 1999. Environmental Assessment for the release and establishment of *Pseudosymnus tsugae* (Coleoptera: Coccinellidae) as a biological control agent for the hemlock woolly adelgid. USDA, Forest Service, Morgantown, WV.

Quimby, J. 1996. Value and importance of hemlock ecosystems in the eastern United States. In: S>M> Salom, T.C. Tigner, and R.C. Reardon, eds. Proceedings of the First Hemlock Woolly Adelgid Review, Charlottsville, VA, 1995. USDA Forest Service, Forest Health Technology Enterprise Team-Morgantown, WV. FHTET 96-10. pp1-8.

Rhea, J.R. 1996. Preliminary results for the chemical control of hemlock woolly adelgid in ornamental and natural settings. In: Salom, S.M., T.C. Tigner, and R.C. Reardon, (Eds.), Proceedings, First hemlock woolly adelgid review, 12 October, 1995, Charlottesville, VA. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-10: 89-102.

Sasaji, H. and M.S. McClure. 1997. Description and distribution of Pseudoscymnus tsugae sp. Nov. (Coleoptera: Coccinellidae), an important predator of hemlock woolly adelgid in Japan. Annals of the Ent. Soc. Am., 90:563-578.

Schroeder, M.E. and R.F. Flattum. 1984. The mode of action and neurotoxic properties of the nitromethylene heterocycle insecticides. Pestic. Biochem. Physiol. 22: 148-160.

Schweitzer,D.1994. Hemlock woolly adelgid and native hemlock lepidoptera. Memorandum to state Natural Heritage Programs and stewardship staff at The Nature Conservancy offices in the ERO states, and NC, SC, GA, and Great Smokey Mountains National Park. (May 19).

Sciascia, J.C. and Ellen Pehek. 1995. Small mammal and amphibian populations and their microhabitat preferences within selected hemlock ecosystems in the Delaware Water Gap National Recreation Area. Draft final report, 39pp.

Silcox, C.A. 2002. Using imidacloprid to control hemlock woolly adelgid in the Eastern United States. In: Onken, B., R. Reardon, and J. Lashomb (eds.), Proceedings, Symposium on the hemlock woolly adelgid In Eastern North America, February 5-7, 2002, East Brunswick, NJ. N.J. Agricultural Experiment Station Rutgers. 280-287 p.

Smith, S.F. and V.A. Krischik. 1999. Effects of systemic imidacloprid on *Coleomegilla maculate* (Coleoptera: Coccinellidae). Envir. Entomol. 28(6): 1189-1195.

Snyder, C., J. Young, D. Smith, D. Lemarie, R. Ross, and R. Bennett. 1998. Influences of eastern hemlock decline on aquatic biodiversity of Delaware Water Gap National Recreation Area. Final Report to the National Park Service.

Tattar, T.A., J.A. Dotson, M.S. Ruizzo, and V.B. Bruce. 1998. Translocation of imidacloprid in three tree species when trunk and soil injected. Journal of Arboriculture 24: 54-56.

Tattar, T.A. and S.J. Tattar. 1999. Evidence of the downward movement of materials injected into trees. Journal of Arboriculture 25(6): 325-332.

USDA Animal and Plant Health Inspection Service. 2002. Draft. Use of Imidacloprid formulations for the control and eradication of wood boring pests: Assessment of the potential for human health and environmental impacts.

Van Driesche, R.G. S. Healy and R.C. Reardon. 1996. Biological Control of Arthropod Pests of the Northeastern and North Central Forest in the United States: A Review and Recommendations. USDA, Forest Service, Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-96-19: 10.

Steward, V.B. and T.A. Horner. 1994. Control of hemlock woolly adelgid using soil injection of systemic insecticides. J. of Arbriculture 20(5):287-288.

Wallace, M.S. and F.P. Hain. 1998. The effects of predators of the hemlock woolly adelgid in north Carolina and Virginia. USDA, Forest Service. Hemlock Woolly Adelgid Newsletter # 3: 3.

Webb, R.E., J.R. Frank, and M. J. Raupp. 2003. Eastern hemlock recovery form hemlock woolly adelgid damage following Imidacloprid therapy. Journal of Arboriculture. 29(5): 298-302.

Yamasaki, M., R.M. DeGraaf, and J.W. Lanier. 2000. Wildlife habitat associations in eastern hemlock – birds, smaller mammals, and forest carnivores. In: Proceedings of a Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America, edited by K.A. McManus, K.S.Shields, and S.R.Souto. pp.135-141.

Young, J.A., D.R. Smith, C.D. Snyder, and D. P. Lemarie. 1998. A landscape-based sampling design to assess biodiversity losses from eastern hemlock decline.